Performance Evaluation and Modeling of Wireless Personal Area Networks

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Outline

- Technology Challenges in Wireless Personal Area Networks (WPANs)
  - Interoperability, interference, support of multimedia applications
- Formal Modeling of Bluetooth
- Coexistence Performance Evaluation of WPANs and WLANs in the 2.4 GHz band.
  - Simulation models (MAC, PHY, Channel)
  - Analysis and Results
- Coexistence Mechanisms
- Conclusions

Key Challenges in WPANs

- Non-interoperable protocols and multiple industry specifications:
  - Bluetooth, HomeRF, IEEE 802.11, DECT, IEEE 802.15 (TG1, TG3, TG4), HIPERLAN.
- Interference in the unlicensed bands:
  - 2.4 GHz ISM Band: Bluetooth, HomeRF, IEEE 802.(11,11-b) devices operating in the same environment lead to significant performance degradation in WPAN and WLAN services.
  - 5 GHz Band: HIPERLAN and IEEE 802.11a, IEEE 802.17, weather radar.

Bluetooth

- Wireless Personal Area Networking
- 1 Mb/s Total Data Rate with TDMA structure
  - Frequency hopping on a packet basis
- Approximately 10 m Range
  - 1 mw to 100 mw Transmitter Power
  - Low Cost Radio Receivers
- Initially Designed for One Hop Operation
  - Star-like Topology
  - 1 Master and up to 7 Slaves
  - Scatternets to allow mutiple hop networks
- Voice and Data Links

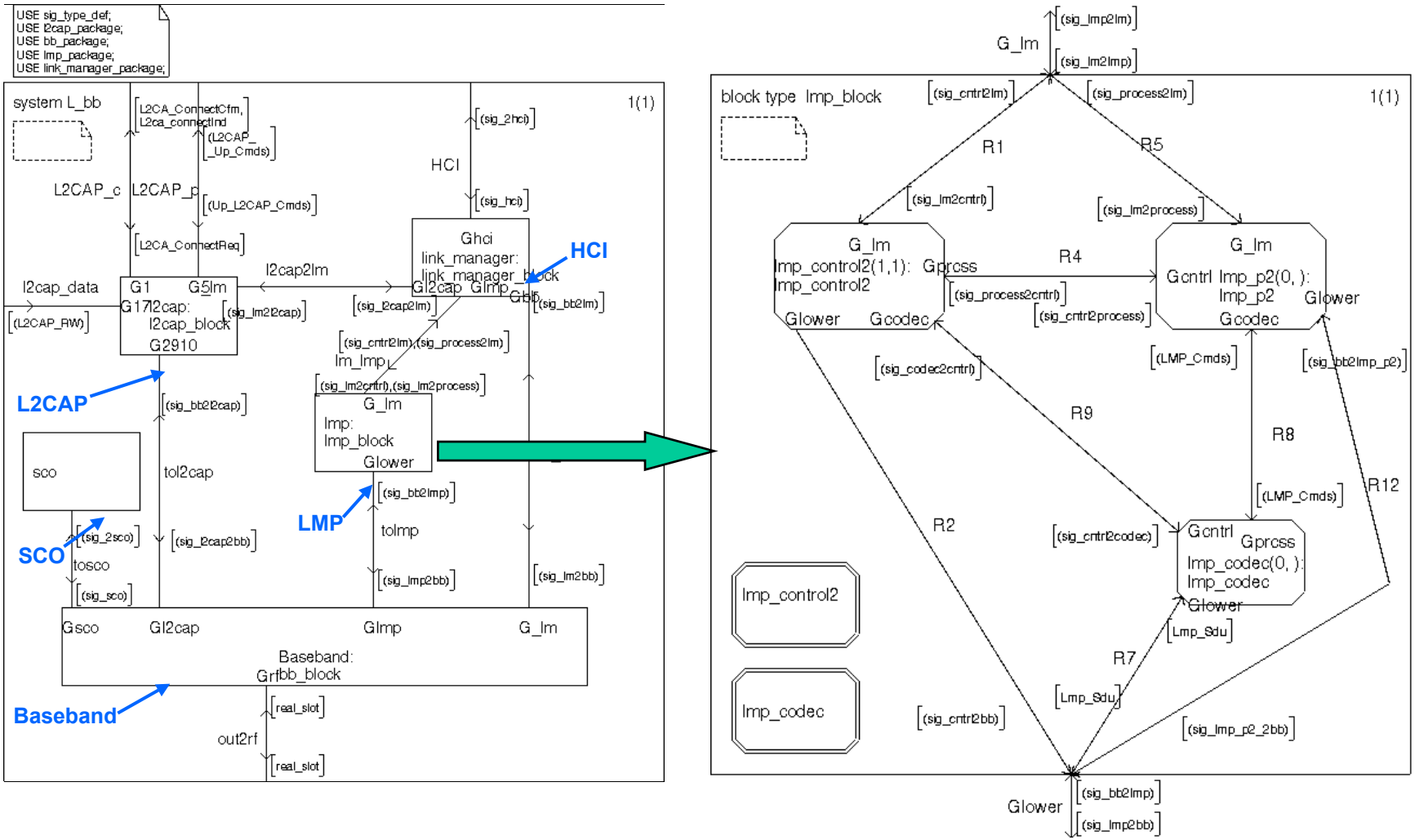
IEEE 802.11b

- Wireless Local Area Network (WLAN)
  - Wireless Ethernet
- 1, 2, 5.5, and 11 Mb/s
  - Direct Sequence Spread Spectrum
  - Complementary Code Keying
- Carrier Sense Multiple Access with Collision Avoidance
  - Also virtual carrier sense using request-to-send (RTS) and clear-to-send (CTS) message
- Range on the order of 100 m
  - Up to 1 W Transmitter Power

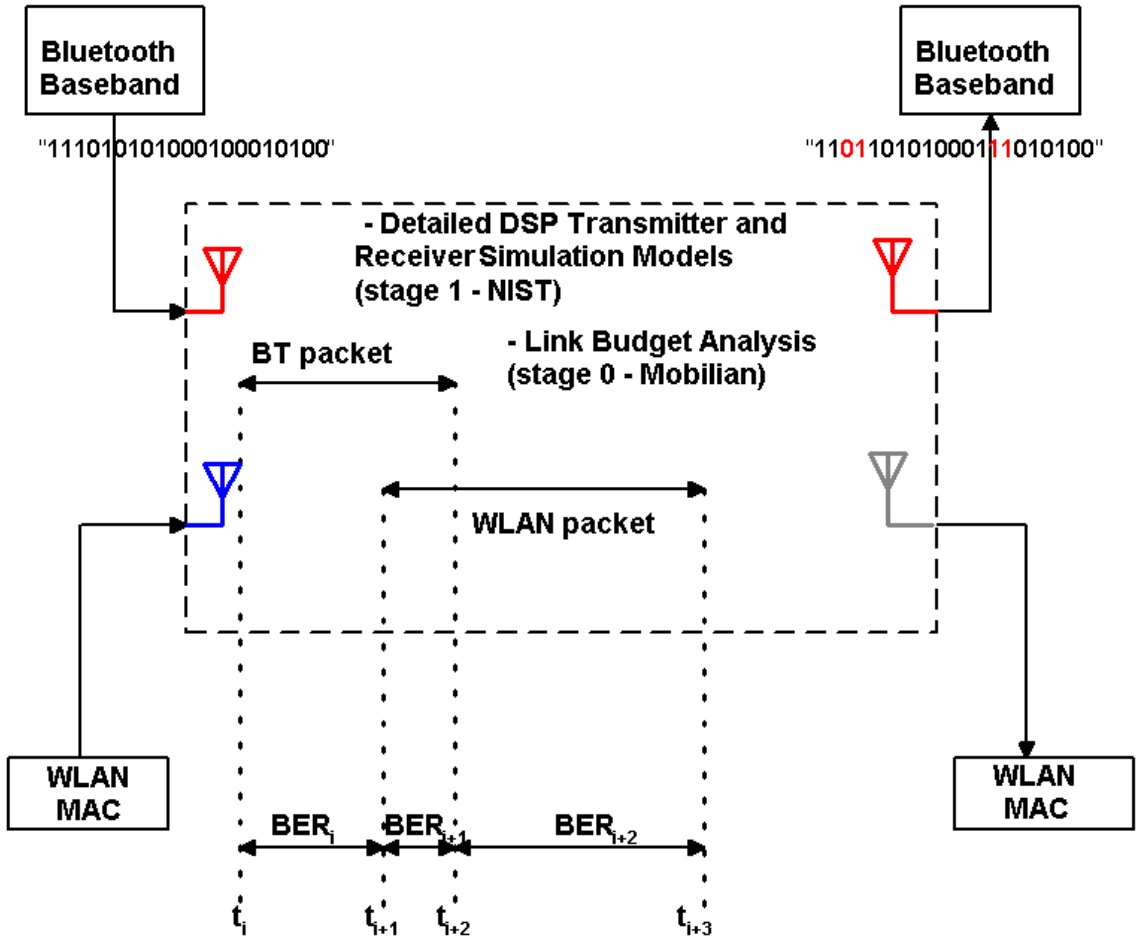
Specification Description Language (SDL)

- Allows formal modeling and (with additional tools) verification of a protocol - Bluetooth
  - Ensure that IEEE 802.15.1 (WPAN) specifications are correct
- Provides a hierarchical view of the protocol
- Can be used to generate a software implementation
- Test scenario creation

Sample SDL Charts



System Simulation Modeling

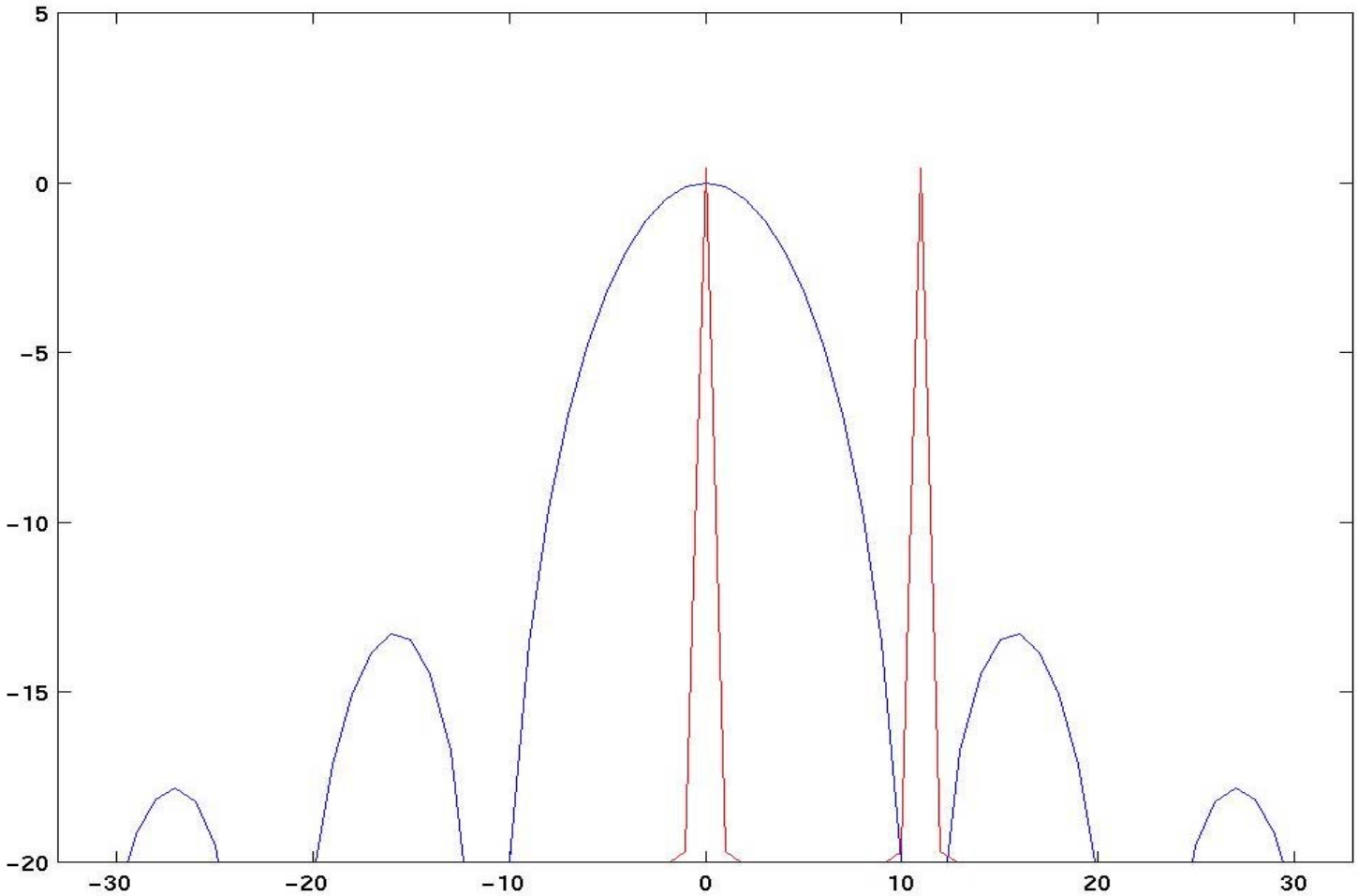


Parameters IN

Main Packet: Type, Power, Frequency, distance(tx,rx)

Interfererence Packet: Type, Power, Frequency, distance(tx,rx), Time Offset

Spectral Domain



Channel Modeling

- Additive White Gaussian Noise, multipath fading
- Path loss model

$$Lp = \begin{cases} 32.45 + 20\log(f.d) & d < 8m \\ 58.3 + 33\log(d/8) & otherwise \end{cases}$$

- Received power and SIR depend on topology and device parameters:

$$P_R = P_T - L_P$$

$$SIR = P_R - P_I$$

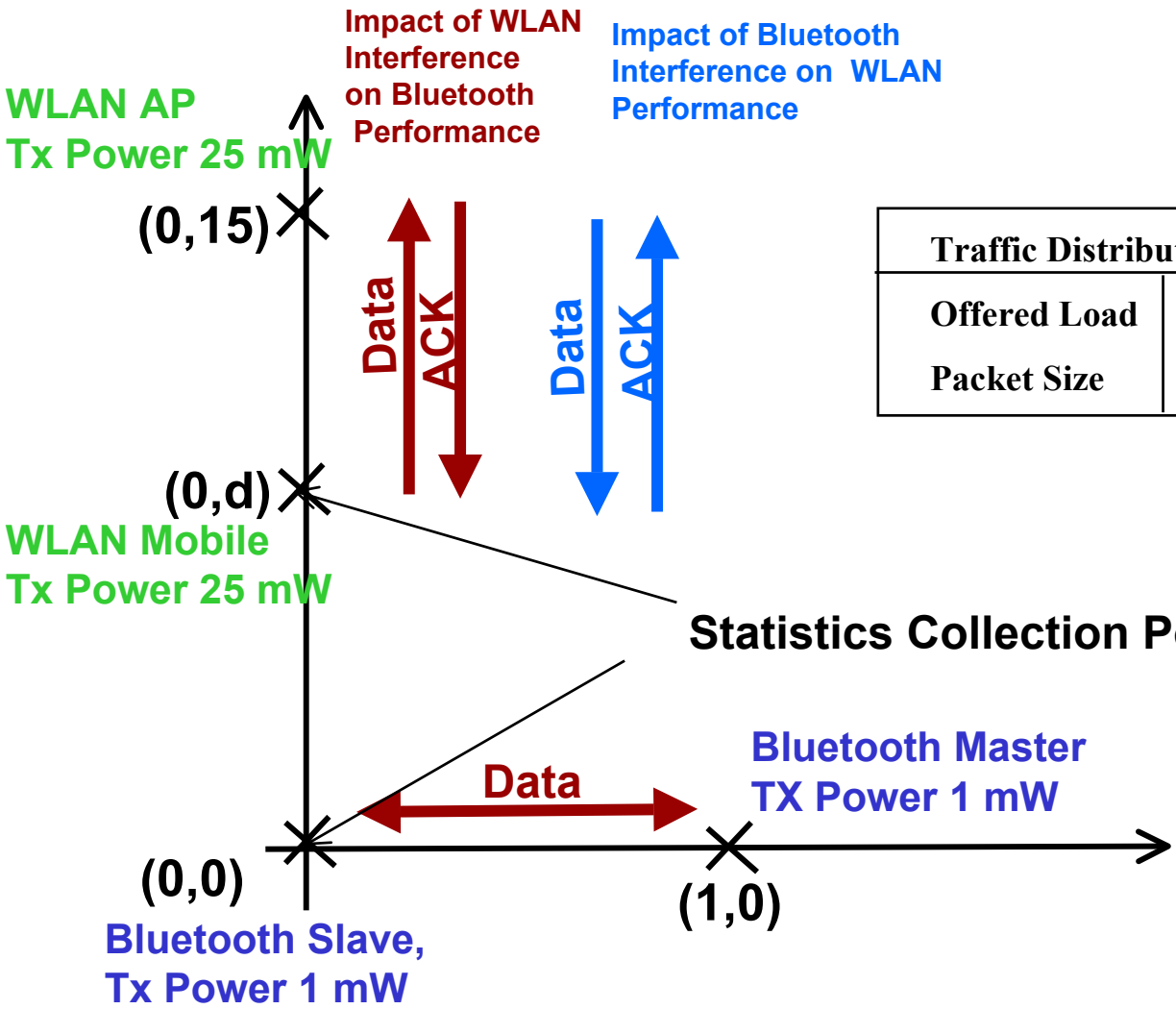
Physical Layer Modeling

- DSP based implementation of transceivers
- Design using typical parameters (goal is to remain non-implementation specific)
- Bluetooth
  - Non-coherent Limiter Discriminator receiver, Viterbi receiver with channel estimation and equalization
- IEEE 802.11
  - Direct Sequence Spread Spectrum (1 Mbits/s)
  - Complementary Code Keying (11 Mbits/s)
  - Frequency Hopping (1 Mbits/s)

MAC Modeling

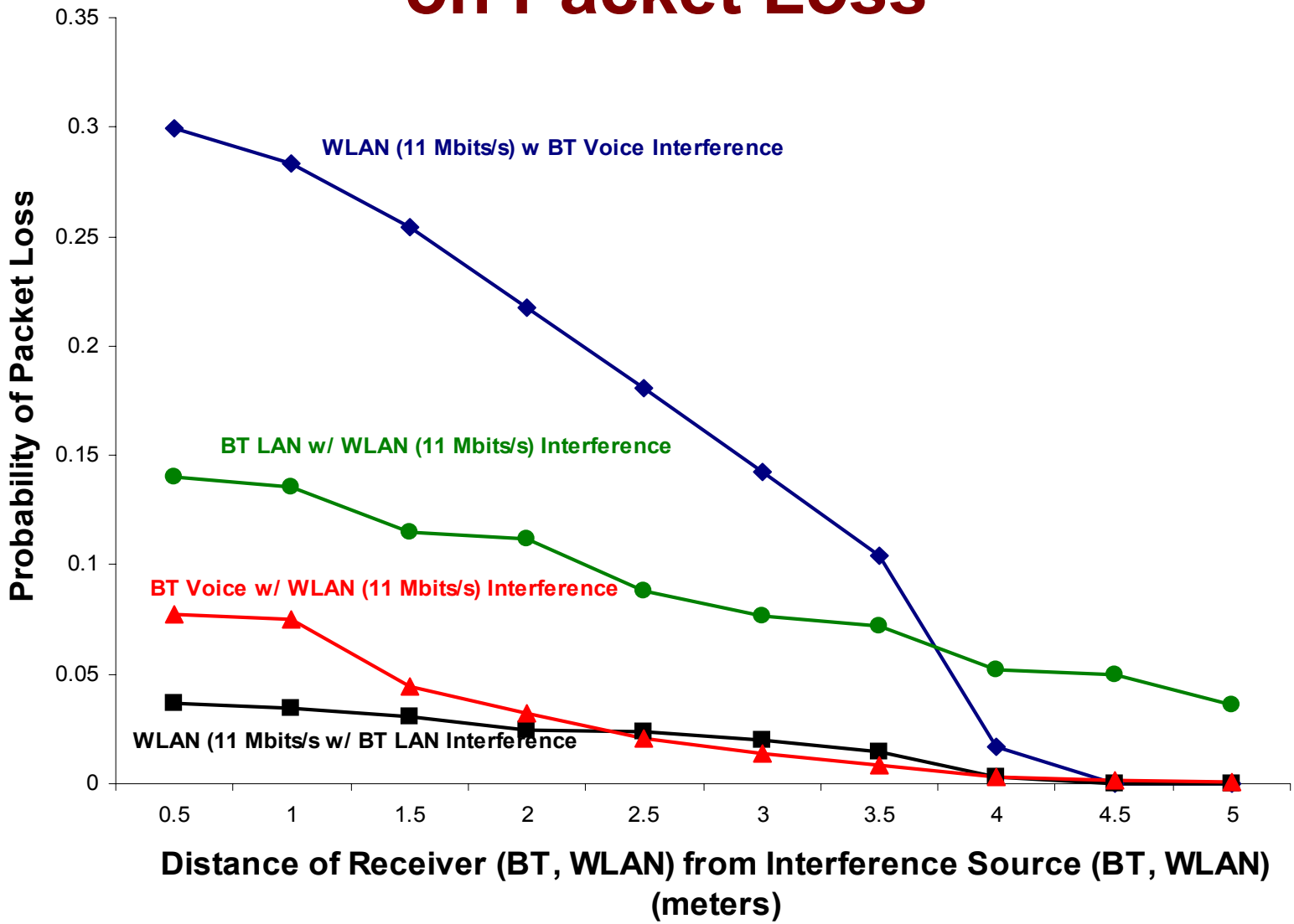
- MAC behavioral implementation for Bluetooth and IEEE 802.11 (connection mode)
- Frequency hopping
- Error detection and correction
  - Different error correction schemes applied to packet segments (Bluetooth)
  - FCS (802.11)
- Performance statistics collection
  - Access delay, packet loss, residual error, throughput

Simulation Scenario

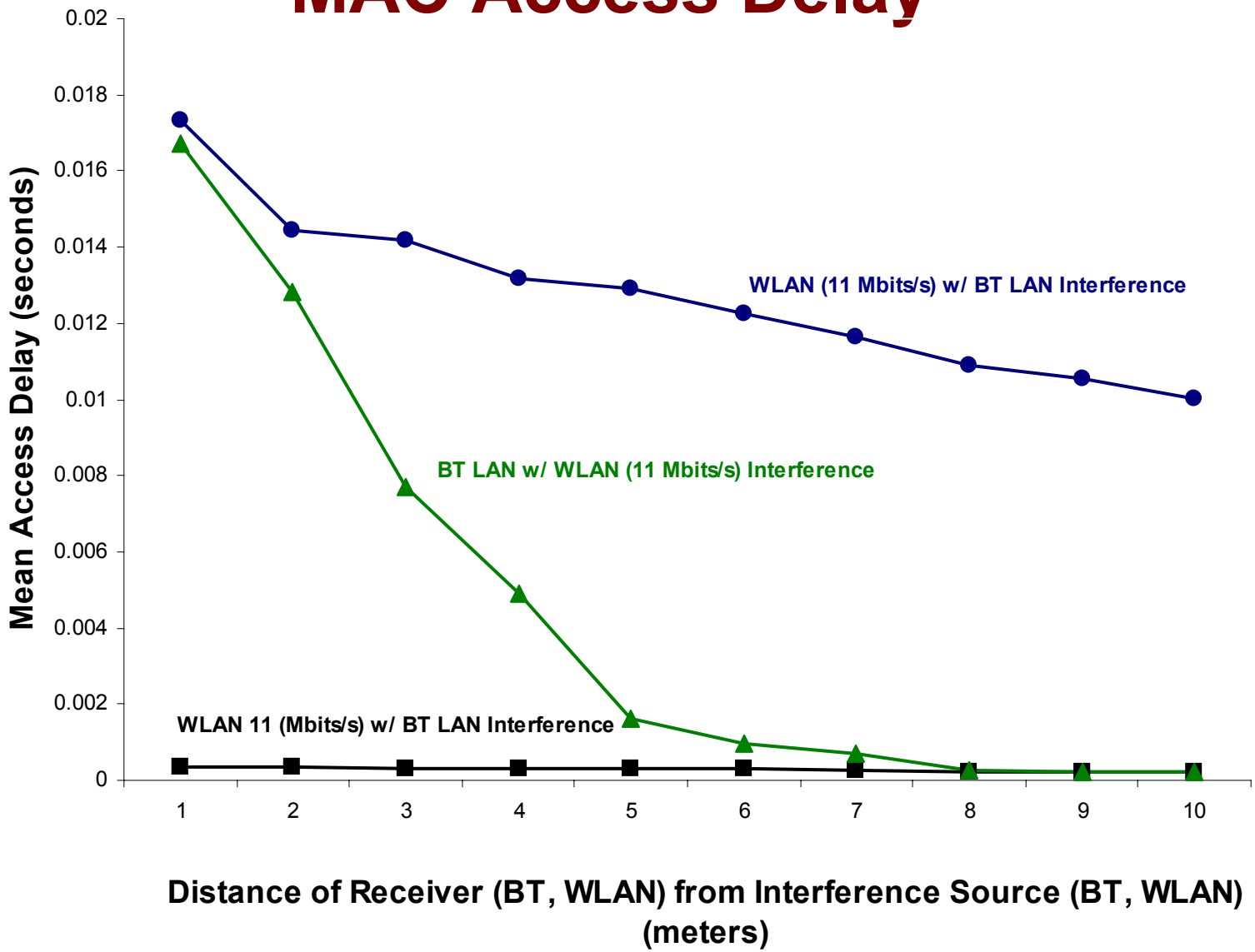


Traffic Distribution for WLAN and BT (LAN)	
Offered Load	30 % Of Channel Capacity
Packet Size	Geometric Distr. Mean 368 bytes

Impact of Interference on Packet Loss



Impact of Interference on MAC Access Delay

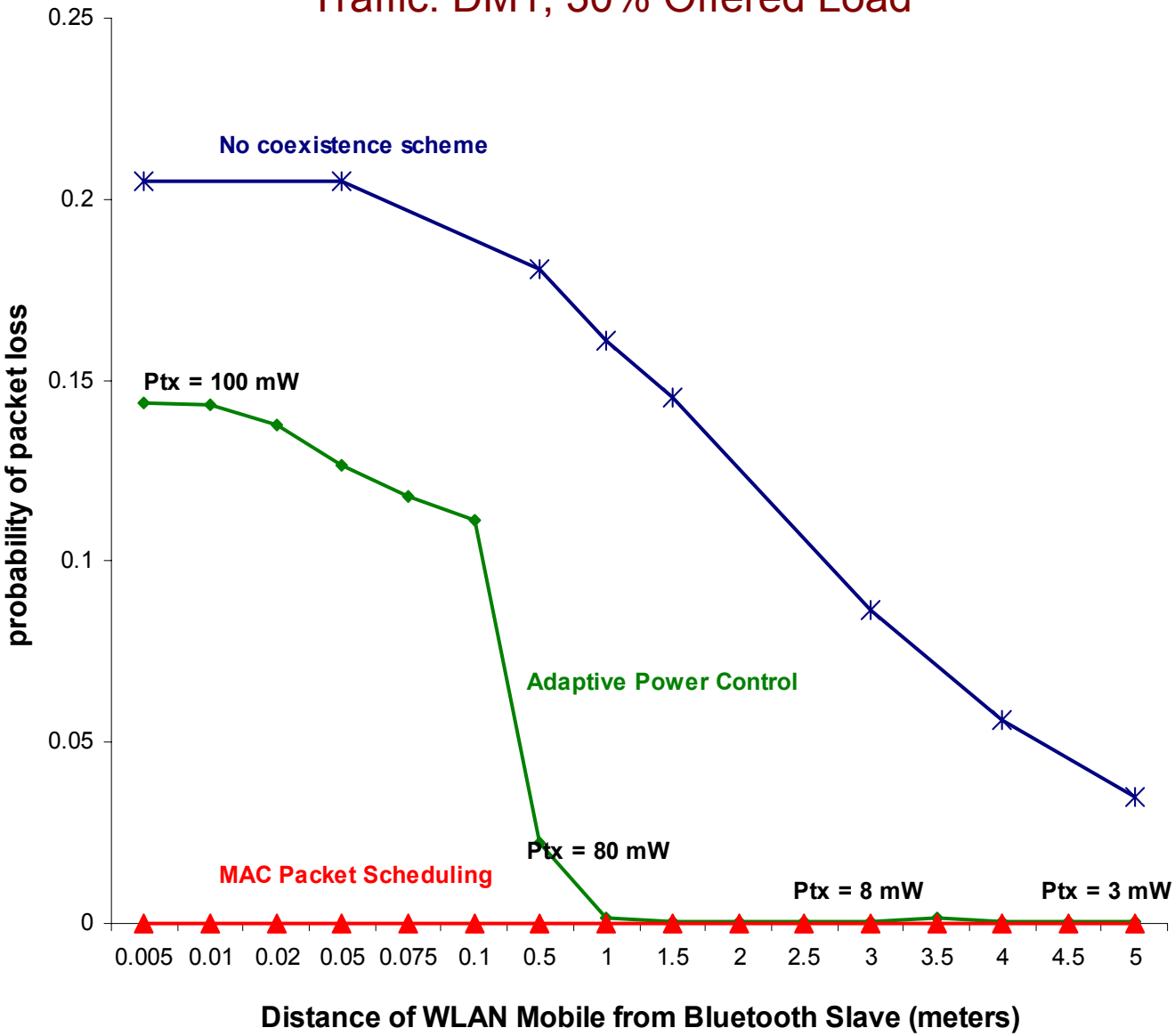


Coexistence Mechanisms

- Collaborative:
  - TDMA solution for scheduling Bluetooth and 802.11 packets on the same device.
  - Notch filtering in 802.11 receiver to remove Bluetooth
- Non-collaborative:
  - Adaptive frequency hopping
  - Varying packet size, data rates, encapsulation
  - MAC scheduling
  - Distributed power control

Packet Loss for Bluetooth:

Traffic: DM1; 30% Offered Load



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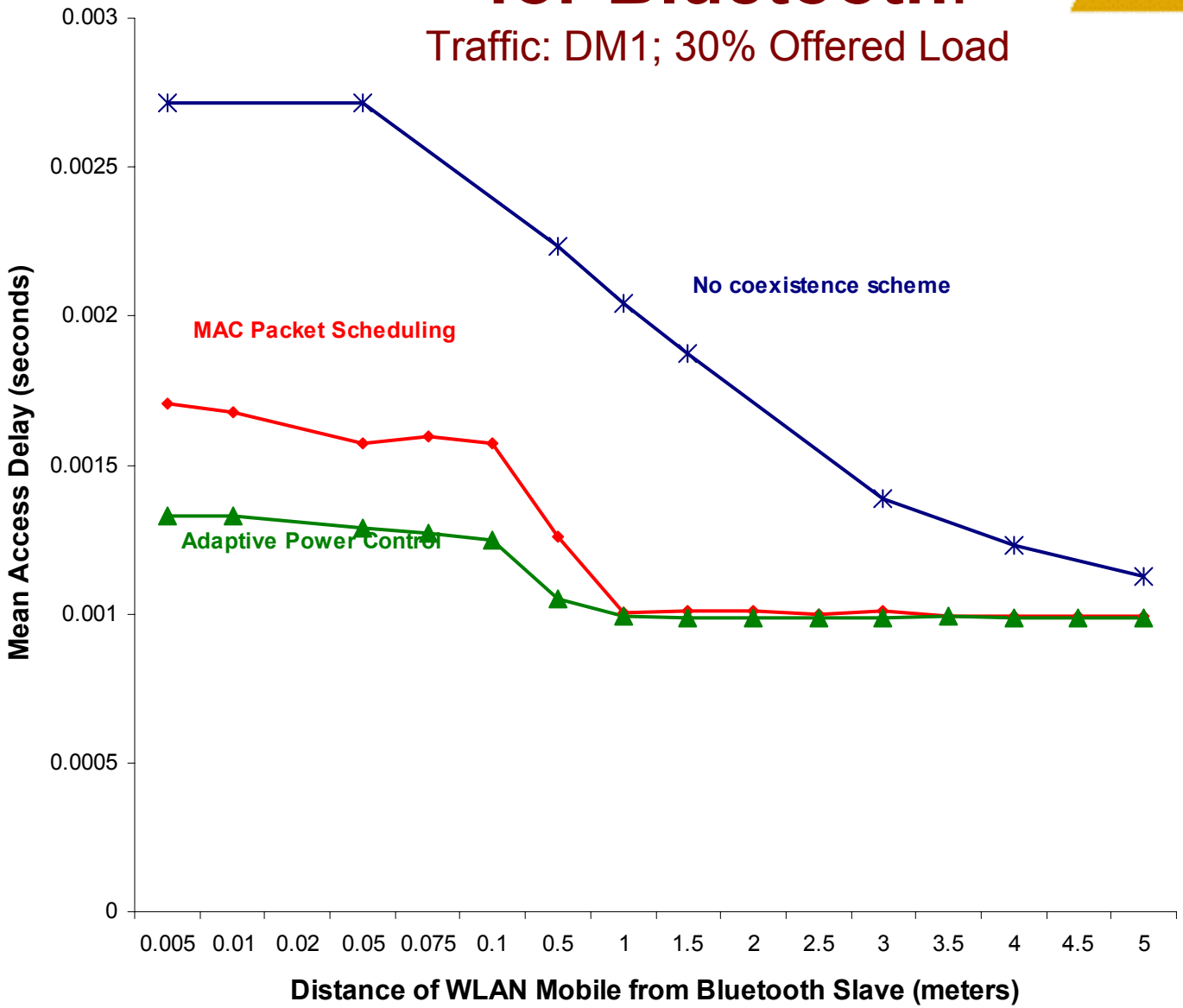

Conclusions

- Bluetooth and 802.11b can cause significant interference to each other
- Coexistence mechanisms can substantially reduce this problem
  - Ongoing work required for Bluetooth voice packets
  - Proposals are being evaluated and refined in IEEE 802.15 Task Group 2
  - Standard practices for operations are being developed
- Having unambiguous specifications is essential
  - Submitted SDLs for Bluetooth to be included as an Annex to IEEE 802.15 TG1 specifications.
- Preparing to release simulation tools to the public.